



LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Fabrication of Planar Laser Targets with Sub-Micrometer Thickness Uniformity

M. J. Bono, C. Castro, R. L. Hibbard

July 28, 2005

2005 American Society for Precision Engineering Annual Meeting

Norfolk, VA, United States

October 9, 2005 through October 14, 2005

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

FABRICATION OF PLANAR LASER TARGETS WITH SUB-MICROMETER THICKNESS UNIFORMITY

Matthew J. Bono, Carlos Castro, and Robin L. Hibbard
Lawrence Livermore National Laboratory, Livermore, California 94550

INTRODUCTION

Lawrence Livermore National Laboratory routinely manufactures planar laser targets that consist of stacked and bonded foils for physics experiments on high-energy lasers. One recent planar laser target, the Equation of State target, had extremely tight specifications. The target required four bonded layers with thickness uniformities of several hundred nm, and the adhesive bonds between the layers could not exceed a few μm . This paper describes the manufacturing process that was developed to meet these specifications.

The target consisted of a copper foil of thickness $43\text{ }\mu\text{m}$ on top of a foil of 1100 aluminum of thickness $62\text{ }\mu\text{m}$. The opposite face of the aluminum was bonded to a foil of iodine-doped polystyrene (ICH) of thickness $102\text{ }\mu\text{m}$. The back side of this foil was bonded to a $32.5\text{ }\mu\text{m}$ foil of pure polystyrene (CH). Each of these components had a diameter of approximately 4 mm , and they were bonded to a gold support ring of diameter 5 mm . A schematic illustration of the target design and a photograph of a finished target appear in Figure 1.

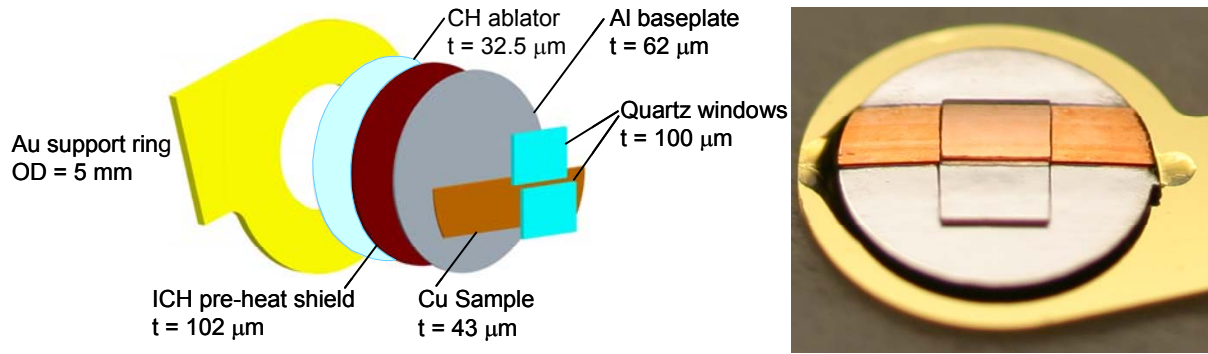


Figure 1. Exploded view of the target design (left) and a photograph of a finished target (right)

In order for the target to perform correctly during the laser shot experiment, each of the foils was required to be of uniform thickness. The specifications for the targets are summarized in Figure 2.

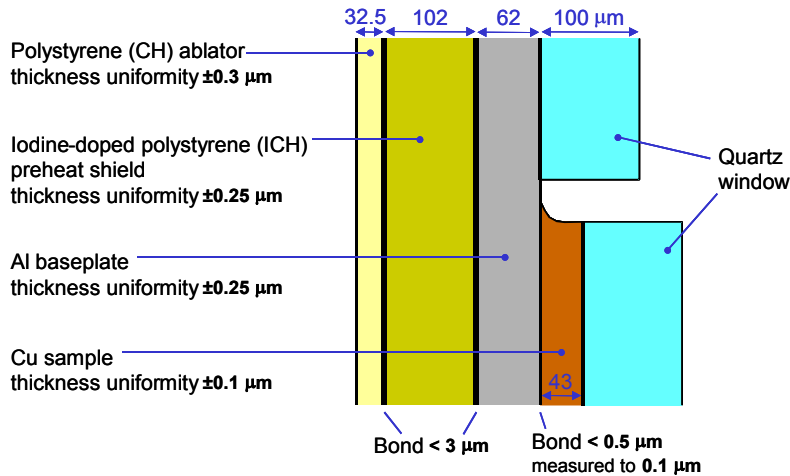


Figure 2. Summary of the specifications for the various layers of the target

The copper sample was required to have a thickness uniformity of $\pm 0.1\text{ }\mu\text{m}$, and the aluminum baseplate was required to have a thickness uniformity of $\pm 0.25\text{ }\mu\text{m}$. Any adhesive layer between the copper and the aluminum was required to be less than $0.5\text{ }\mu\text{m}$ and had to be measured to better than $0.1\text{ }\mu\text{m}$. The bonds that held the ICH and CH layers in place were required to be less than $3\text{ }\mu\text{m}$. The specifications for the dimensions and metrology of these

targets represented a level of precision an order of magnitude beyond that required for most laser targets, so they could not be manufactured using standard target fabrication practices.

WORKPIECE FIXTURING

Meeting the thickness uniformity specifications required a carefully planned manufacturing process. Many different fabrication methods were considered before selecting one that used a combination of diamond turning, deposition, and precision assembly. The targets were built upon an aluminum disk of diameter 100 mm and thickness 6 mm, which eventually became the 62 μm baseplate of the targets. To obtain the required accuracy, all machining was performed on a diamond turning machine outfitted with a specially designed vacuum chuck to hold the 100 mm aluminum workpiece, as shown in Figure 3. The vacuum chuck had lands of width 50 μm , because lands this small were known to be able to hold flat workpieces with a repeatability of 25 nm when used properly. The workpiece diameter of 100 mm allowed the disk to be handled easily, so it could be inserted and removed from the vacuum chuck with the required accuracy. The large diameter also had the advantage that any axial runout of the workpiece due to a seating error on the vacuum chuck would correspond to a small angular error. The large workpiece also contained sufficient area to measure its seating on the vacuum chuck using a capacitance probe, which was required to metrologize the targets correctly. And finally, a large number of 4 mm diameter targets could be fabricated from a single 100 mm disk.

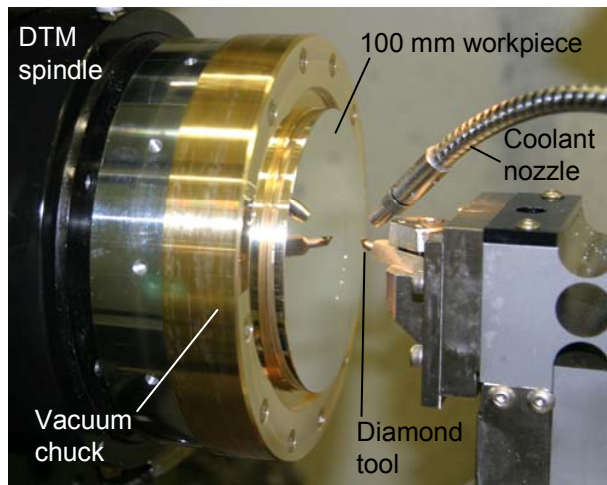


Figure 3. Diamond turning of a 100 mm diameter aluminum workpiece on a custom vacuum chuck

Obtaining the required thickness uniformity and meeting the metrology requirements for each of the different layers of the target required that the base upon which the targets were built be very precise. Therefore, the two faces of the 100 mm aluminum disk had to be machined parallel to each other. To obtain parallel faces, the disk was diamond turned, flipped over on the vacuum chuck, and then diamond turned again. This process was repeated several times until adequate parallelism was achieved. Each time the disk was removed and placed back onto the vacuum chuck, the axial runout of the disk was measured using a capacitance probe to quantify the seating of the part on the vacuum chuck and the parallelism of the two faces of the disk. Using this method, the two faces of the disk were machined parallel to within 0.1 μm .

DEPOSITION OF THE COPPER SAMPLE

Once a precise 100 mm aluminum disk had been obtained, the copper sample was fabricated. As shown in Figure 1, the copper sample had a thickness of 43 μm and a width of 1 mm. The physics of the laser experiment required that any adhesive between the copper sample and the aluminum baseplate have a thickness of less than 0.5 μm , which had to be measured to within 0.1 μm . To avoid the difficulties associated with obtaining such a thin adhesive bond and measuring it with the required accuracy, the copper was deposited directly onto the aluminum.

Several different deposition processes were investigated, including e-beam evaporation, electroplating, and various sputtering techniques. Each of these techniques had advantages and disadvantages that needed to be considered. The high temperatures associated with e-beam evaporation made it difficult to maintain the form of the aluminum substrate. Electroplating cannot be adequately performed onto the non-conductive oxide layer on aluminum, so the aluminum substrate must first be coated with an intermediate material, such as zinc. However, these targets could not tolerate the surface roughness created by zincation. Sputtering produces an excellent interface between copper and aluminum, and excellent adhesion can be obtained by ion milling the aluminum prior to sputtering. Unfortunately, sputtering processes are normally used to create sub- μm coatings, and large residual stresses are often created if the coating exceeds a thickness of a few μm .

After performing several tests with each of these methods, a technique was developed that used a combination of sputtering and electroplating. In the sputter-seeded electroplating approach, several μm of copper were first sputtered onto the aluminum, and additional copper was then electroplated onto the sputtered copper. The electroplated copper was then diamond turned to the proper size and form. There were many details of this process that had to be worked out in order to meet the requirements for the targets. The first issue that had to be addressed was obtaining adequate adhesion between the sputtered copper and the aluminum. Testing revealed the importance of removing the residual traces of cutting fluid from the surface of the aluminum, so the disk was carefully cleaned

by rinsing it several times with pentane, acetone, and ethanol. The oxide layer on the aluminum had to be removed prior to sputtering, which was accomplished by ion milling the surface of the aluminum in the sputtering chamber. And finally, a 20 nm layer of titanium was sputtered onto the aluminum before sputtering the copper. This thin layer of titanium did not have a noticeable effect on the performance of the target during the laser experiments, but it promoted adhesion between the aluminum and the copper.

One issue that required careful attention was the development of a masking method for the electroplating process that produced a clean edge on the copper sample while maintaining a diamond turned finish on the aluminum baseplate. The chemicals used in the electroplating process react harshly with aluminum and can cause a great deal of corrosion pitting. Several tests revealed that these chemicals damaged an aluminum substrate by penetrating through or beneath masks composed of various paints or tapes that are normally used for electroplating.

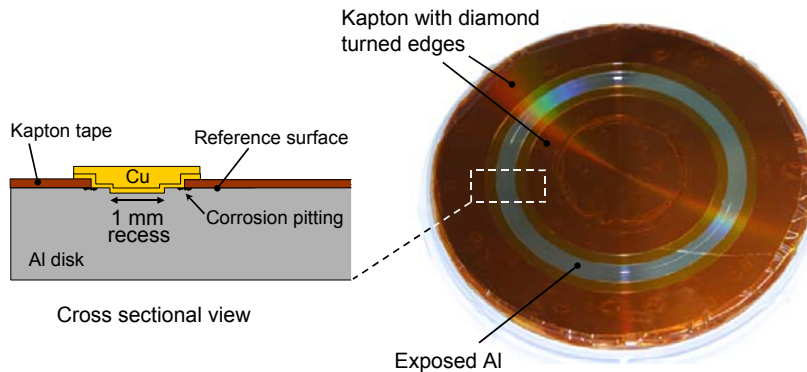


Figure 4. Masking of the workpiece prior to sputtering

To solve this problem, the copper sample was deposited into a 1 mm wide recess that had been diamond turned into the aluminum disk. A mask of Kapton tape was placed on either side of the recess prior to the sputtering operation, as shown in Figure 4. Kapton tape was selected for the mask because its outgassing and thermal properties are consistent with the conditions of the sputtering process. As shown in the figure, the copper was deposited into a groove of depth 25 μm with a width of 1 mm located at a diameter of 63 mm.



Figure 5. Diamond turned copper

The masked disk was placed into the sputtering chamber, where it was ion milled for several minutes to remove the oxide layer from the aluminum. A layer of 20 nm of titanium was then sputtered onto the aluminum, followed by 3 μm of copper. The 100 mm disk was then placed into a special hardmask that sealed off its back and side surfaces, and the disk was submerged in the electroplating bath to add an additional 100 μm of copper on top of the sputtered copper, as shown in the left side of Figure 4. The disk was then removed from the hardmask and placed back on the diamond turning machine.

After removing the Kapton tape and cleaning off the adhesive residue, a capacitance probe measured the axial runout of the disk to verify that it was seated correctly on the vacuum chuck. As expected, the electroplating chemicals created corrosion pits in the aluminum with a depth of several μm adjacent to the Kapton mask. It is for this reason that the copper had been deposited into a recess of depth 25 μm . The diamond tool was used to machine the copper to the proper size and form, as shown in Figure 5. At the same time, the 25 μm of aluminum adjacent to the recess was diamond turned so that the surface of the aluminum was coplanar with the bottom surface of the copper. An LVDT mounted on the B-axis of the diamond turning machine measured the step heights from the newly diamond turned surfaces of the copper and aluminum to a reference surface on the aluminum disk. The measurements indicated that the thickness uniformity of the copper was within the ± 50 nm uncertainty of the measurement, and the aluminum baseplate was flush with the bottom of the copper to better than 100 nm.

MACHINING AND ASSEMBLY

The workpiece and the vacuum chuck were then removed from the diamond turning machine, and a new vacuum chuck was installed. This new vacuum chuck was diamond turned to match the contour of the workpiece, including a 43 $\mu\text{m} \times 1$ mm recess for the band of copper. The vacuum grooves on the chuck had a width of 100 μm , and the lands had a width of 50 μm . After placing the 100 mm disk onto this vacuum chuck, a capacitance probe indicated that the axial runout of the part was 0.15 μm at a diameter of 63 mm, which verified that the required thickness uniformity of the aluminum baseplate could be achieved. The 6 mm of aluminum was then machined to a thickness of 62 μm , as shown in Figure 6. A high-speed steel tool was used to remove most of the material. The finishing passes were performed using a diamond tool with a nose radius of 25 μm and a depth of cut of 2 μm .

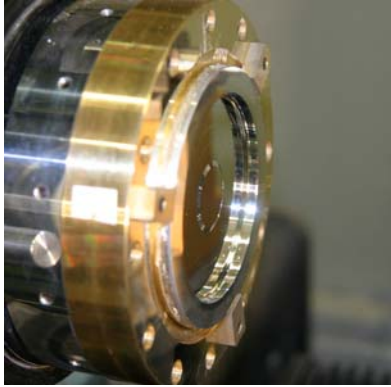


Figure 6. 100 mm diameter disk after being diamond turned to a thickness of 62 μm

could remain in the vacuum chuck, all reference surfaces could be maintained, and the machine tool slides and the C-axis (the spindle axis) could be used to perform the assembly operations with sub- μm positioning precision. The assembly station incorporated an air bearing in series with a spring and a force transducer so that the operator could control the assembly force with an accuracy of approximately 0.01 N ^[1].

Once the assembly cone containing the ICH pad was installed on the assembly station, a drop of epoxy was placed onto the chamfered surface of the pad. The ICH pad was pressed into the aluminum with a force of 0.1 N and translated 0.75 mm back and forth across the surface several times in order to reduce the amount of epoxy between the ICH pad and the aluminum substrate. The pad was left in this position for several hours until the epoxy had cured. The assembly cone was then removed, and the step height from the surface of the pad to the aluminum was measured using an LVDT mounted on the B-axis platform in order to verify that the thickness of the epoxy was less than the required 3 μm . The ICH pad was then diamond turned to a thickness of 102 μm , and its thickness and thickness uniformity were measured with the LVDT. The process was then repeated to bond a CH pad on top of each ICH pad, and then the CH pads were diamond turned to a thickness of 32.5 μm and measured with the LVDT. Because the surfaces of the aluminum, ICH, and CH were each diamond turned without ever removing the workpiece from the vacuum chuck, these surfaces were machined parallel to each other to within the ± 50 nm uncertainty of the LVDT measurements.

To create the individual laser targets, each of the subassemblies was cut from the 100 mm disk using an excimer laser. Each subassembly had a diameter of 4 mm and consisted of the 32.5 μm CH foil, the 102 μm ICH foil, the 62 μm aluminum foil, and the 43 μm band of copper of width 1 mm. Two quartz windows of thickness 100 μm were then bonded onto the aluminum and the copper, as shown in Figure 1. The 4 mm diameter subassembly was then bonded to a gold support ring to complete the laser target.

CONCLUSIONS

The Equation of State laser targets consisted of planar layers of copper, aluminum, iodine-doped polystyrene, and pure polystyrene. The required thickness uniformities of the various layers of the target ranged from ± 0.1 μm to ± 0.3 μm , and they had to be measured with this same level of accuracy. To meet the requirements for the interface between the aluminum and the copper, a sputter-seeded electroplating process was developed to deposit copper onto the aluminum. The thickness uniformity requirements for the various layers were obtained by fabricating the targets on a 100 mm diameter disk that was held on the diamond turning machine using a carefully designed vacuum chuck. By performing assembly operations and metrology directly on the diamond turning machine, the workpiece could remain in the vacuum chuck throughout the manufacturing process. Therefore, the reference surfaces required for the fabrication and metrology of the targets could be maintained.

ACKNOWLEDGEMENT

Significant contributions to this work were made by Ron Foreman, Johann Lotscher, Rudy Robles, Joe Satcher, Stuart Gammon, Bob Reibold, and Brian Kelly. This work was performed under the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory, under Contract No. W-7405-Eng-48.

REFERENCE

- [1] M. Bono, and R. Hibbard, "Machining, Assembly, and Characterization of a Meso-Scale Double Shell Target" *Journal of Manufacturing Processes*, Vol. 6, No. 4, pg. 97-106, 2004.